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U.S. COAL USE: THE ENVIRONMENTAL CHALLENGE

by

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16. ABSTRACT

Although the paper focuses on past (since 1920) and current coal use and pollutant emissions in the U.S., it also discusses where the U.S. may be going in terms of pollutant emissions over the next several decades. Conclusions of this look at coal use include the fact that increasing coal use is vital to the economic well being of the U.S. With proper application of controls, coal use can be increased as projected without unacceptable levels of sulfur and nitrogen oxides, particulate, and nitrous oxide. However, the forecast is bleaker for carbon dioxide and its projected impact on global warming. Barring a technology breakthrough of major proportions (e.g., successful commercialization of nuclear fusion or solar electric generation), the best that can be envisioned is to moderate carbon dioxide emissions from the combustion of coal and other fuels through conservation.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Pollution	Nitrogen Oxides	Pollution Control	13B
Fossil Fuels	Nitrogen Oxide (N_2O)	Stationary Sources	21D
Combustion	Particles	Particulate	21B
Coal Deposits	Carbon Dioxide		08G
Emission			14G
Sulfur Oxides			07B

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U. S. Coal Use Since 1920

Coal in the United States is the most plentiful domestic fossil fuel, with reserves far in excess of those associated with petroleum and natural gas. Coal has been a key fuel since the industrial revolution. However, its relative role compared to petroleum and more recently natural gas has changed substantially over the last 50 years. Figures 1 and 2 show actual fuel use in the U. S. in 1935 and 1975. Figure 3 projects fuel use in the year 2010 using what, at least at this time, appear to be reasonable assumptions. These energy flow sheets show the quantities of each major fuel utilized in quads (10^{15}Btu). They also graphically depict the fraction converted to electrical energy, and the end use of both electricity and the unconverted fuels in the commercial/residential, industrial, nonenergy, and transportation end-use sectors. As one can see, the relative role of coal decreased substantially between 1935 and 1975 as petroleum and natural gas became more abundant at relatively low prices. You will also note a tremendous increase in overall energy consumed in that time period from 18 to 73 quads. Also, electrical generation increased by a factor of almost 20 in that 40 year period with electrical generation coming in 1975 from a variety of fuels. Coal, gas, oil, nuclear, and hydro were all significant energy sources for electrical production. Also note the dramatic increases in oil and natural gas use in this 40 year period.

There is significant evidence that this trend away from coal and toward natural gas and oil has already been reversed. Figure 4 shows U. S. coal use per person. Note that 1960 was a turning point initiating a trend toward increased per capita coal use: coal use had decreased since 1920, peaked during World War II, and decreased steadily until 1960 when this trend was reversed. I believe that the projections in Figure 3 are credible in that they show natural gas and oil (much of it imported) being kept at levels close to current use. The projection also suggests a relatively modest growth in total energy consumed to a little over 100 quads. The incremental fuel use associated with the growth between 1975 and 2010 is primarily associated with increased coal and renewable fuel use. The renewable category includes hydroelectric, wood, solar, and geothermal energy sources.

Figure 5 provides a more detailed look at U.S. coal use between 1920 and 1985. One can see the gradual decrease in coal use in the 1950s and 1960s, with substantially increased coal use since 1965. Also note that the end-product use of coal has changed substantially during this century. Earlier this century, coal was used primarily for industrial boilers, for heating commercial and residential facilities, for railroad and steamship propulsion, and to provide raw material for the iron and steel industry. Coal consumption has changed dramatically over the last couple of decades. Currently, by far the most significant use of coal is for the generation of electricity. Non-electrical uses of coal are limited to modest amounts to fire industrial boilers and even more modest quantities for commercial/residential heating and iron and steel production. You will also note that Figure 5 shows a major rise in coal use during 1940-45 reflecting enhanced industrial activity during World War II.

Between 1920 and 1985, coal costs have been substantially lower on a Btu basis (kilojoule) than oil costs. Since 1930 they have generally been about 50 to 30 percent that of oil. The historical costs of the three major domestic fuels are shown in Figure 6. Also note that natural gas became readily available in large quantities in the post-World War II period, originally at quite low

FIGURE 1. U.S. ENERGY FLOW--1935
(Quads)

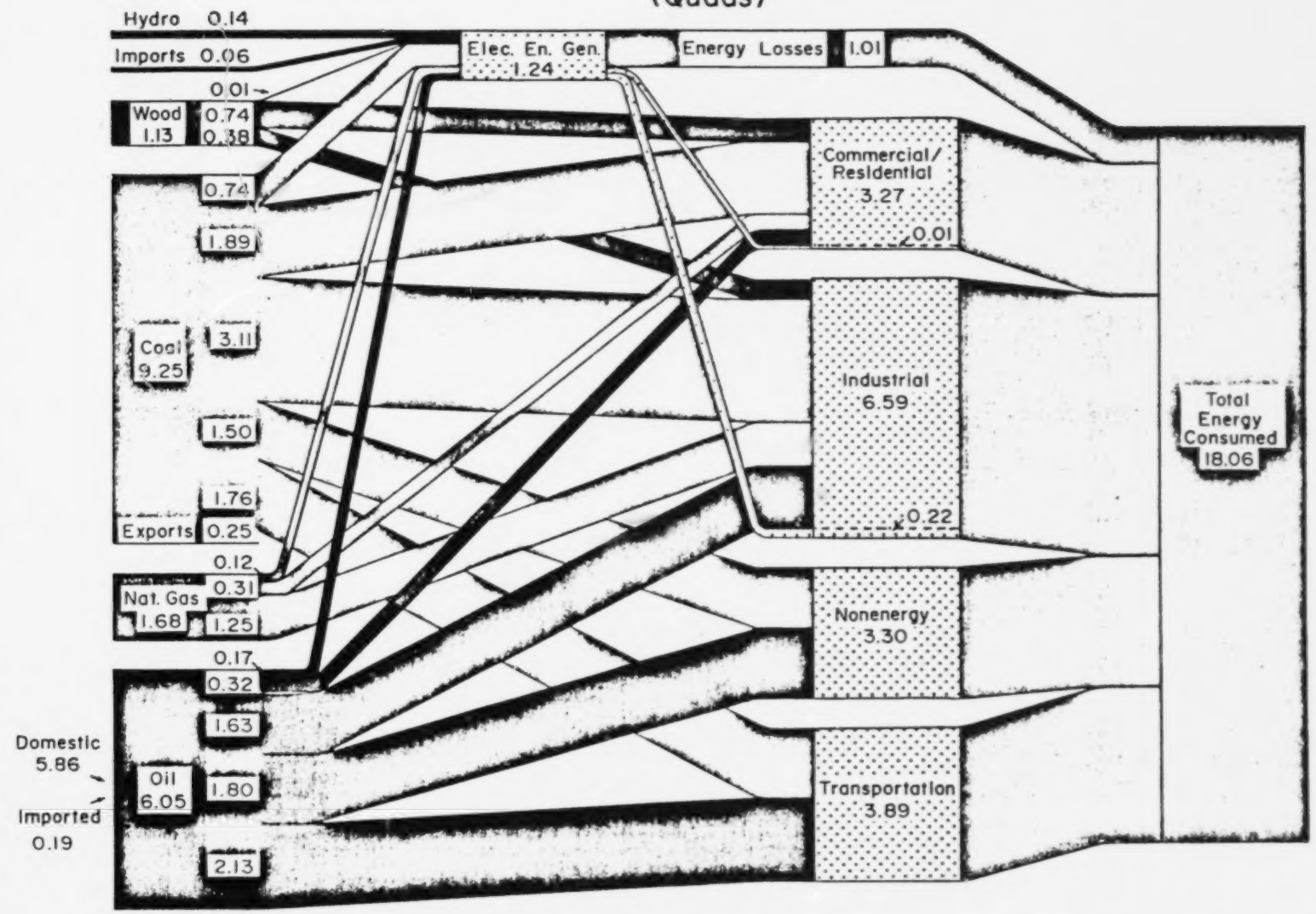


FIGURE 2. U.S. ENERGY FLOW--1975
(Quads)

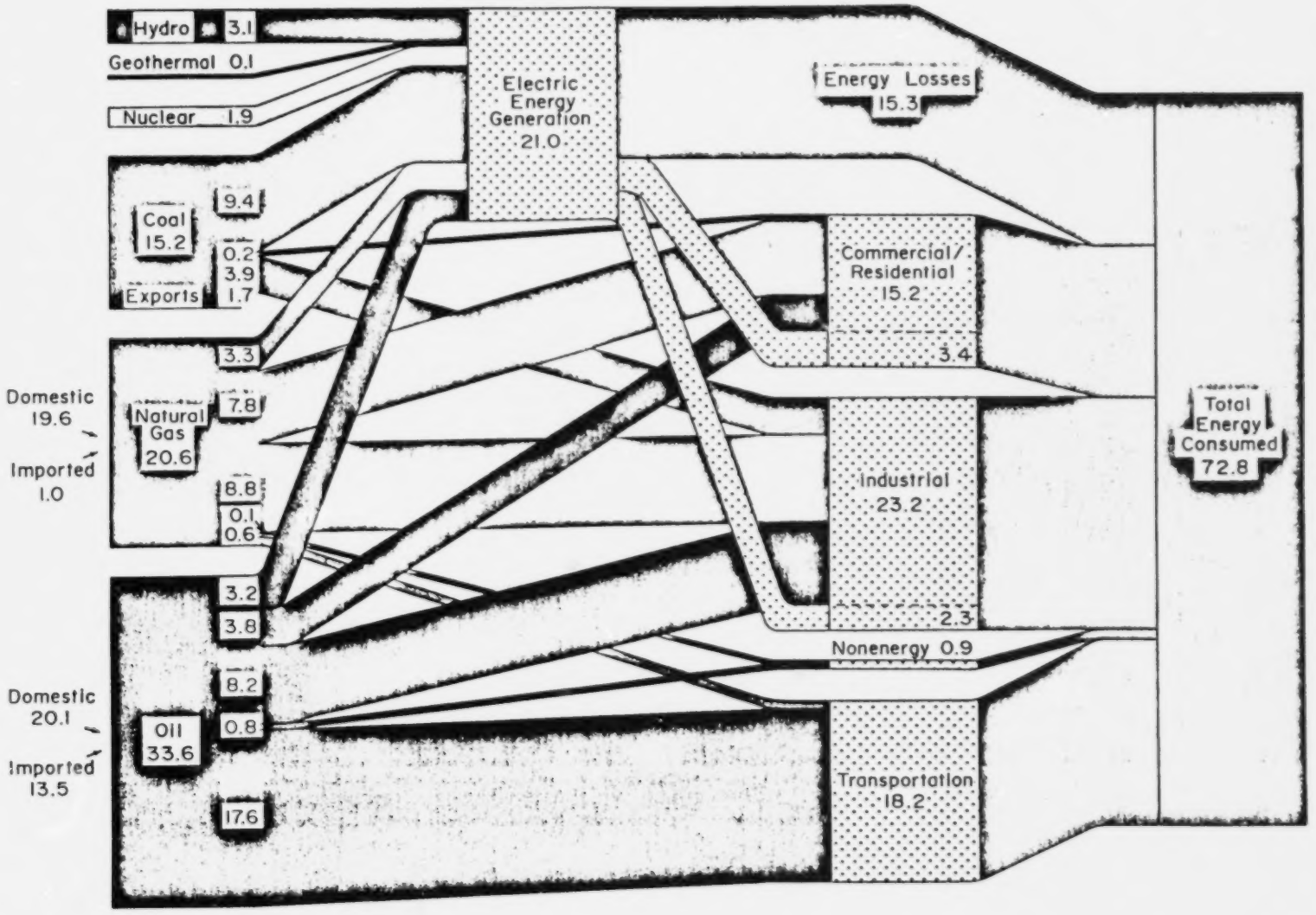


FIGURE 3. U.S. ENERGY FLOW--2010
(Quads)

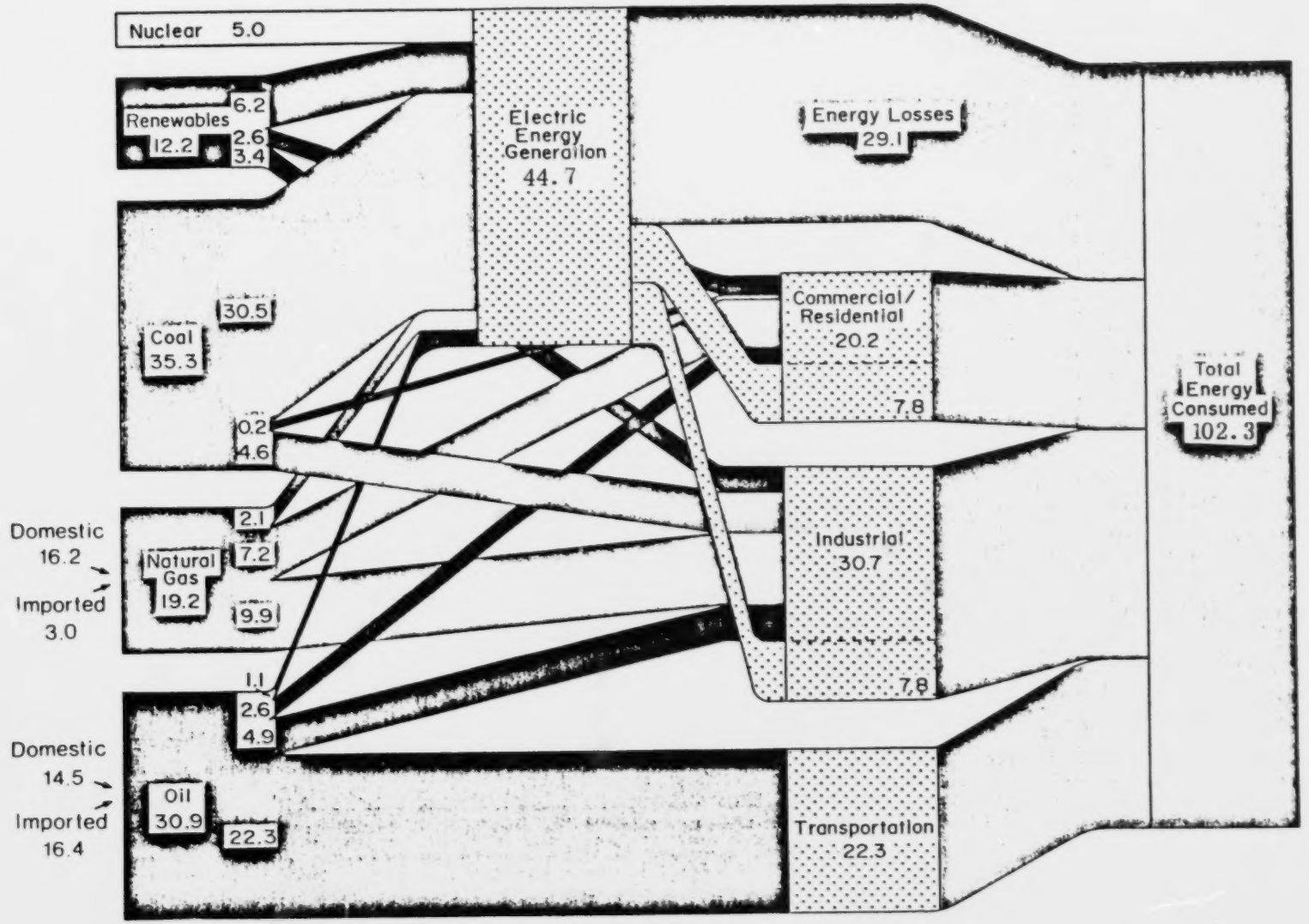
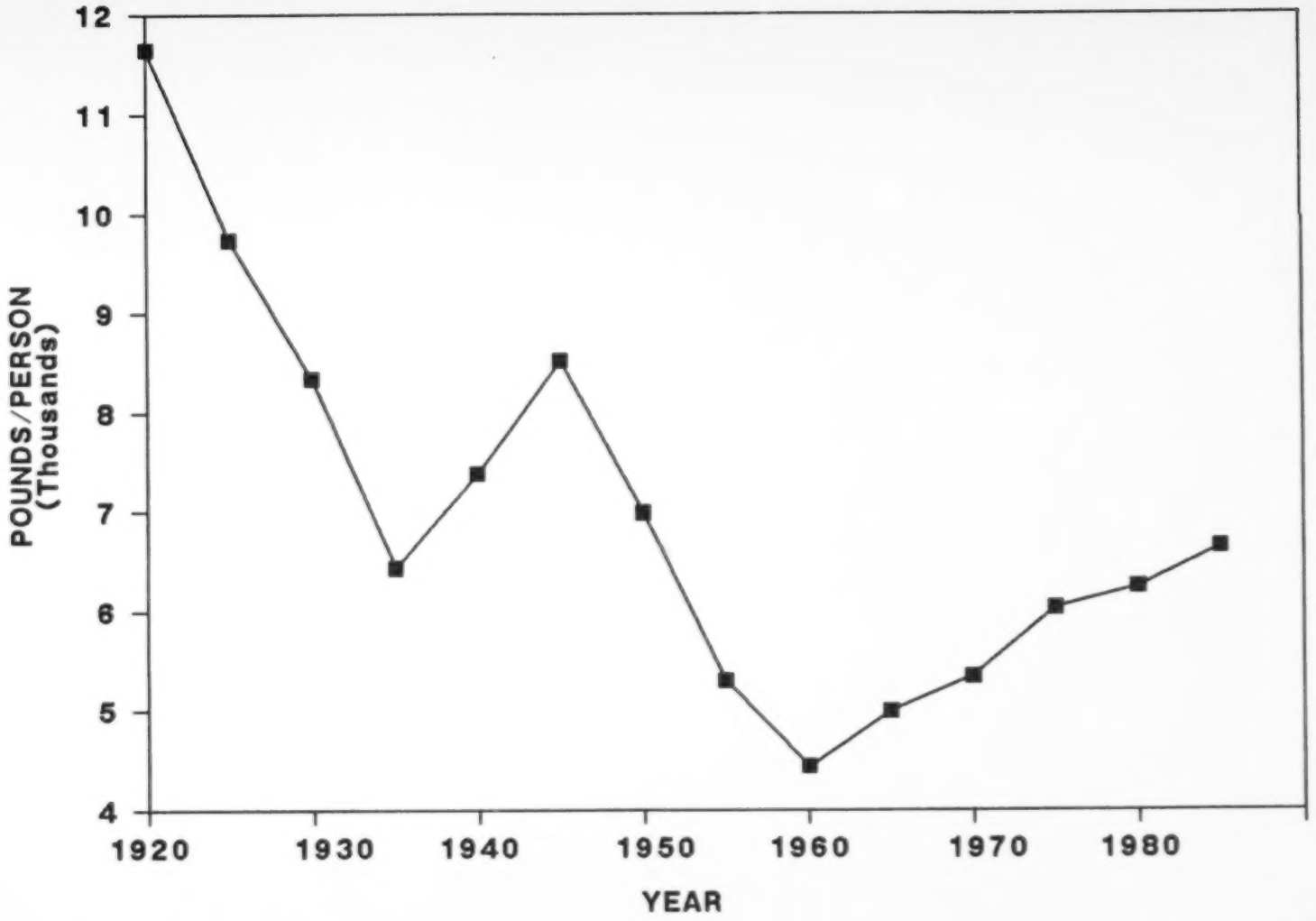


FIGURE 4. **U.S. COAL USE PER PERSON**



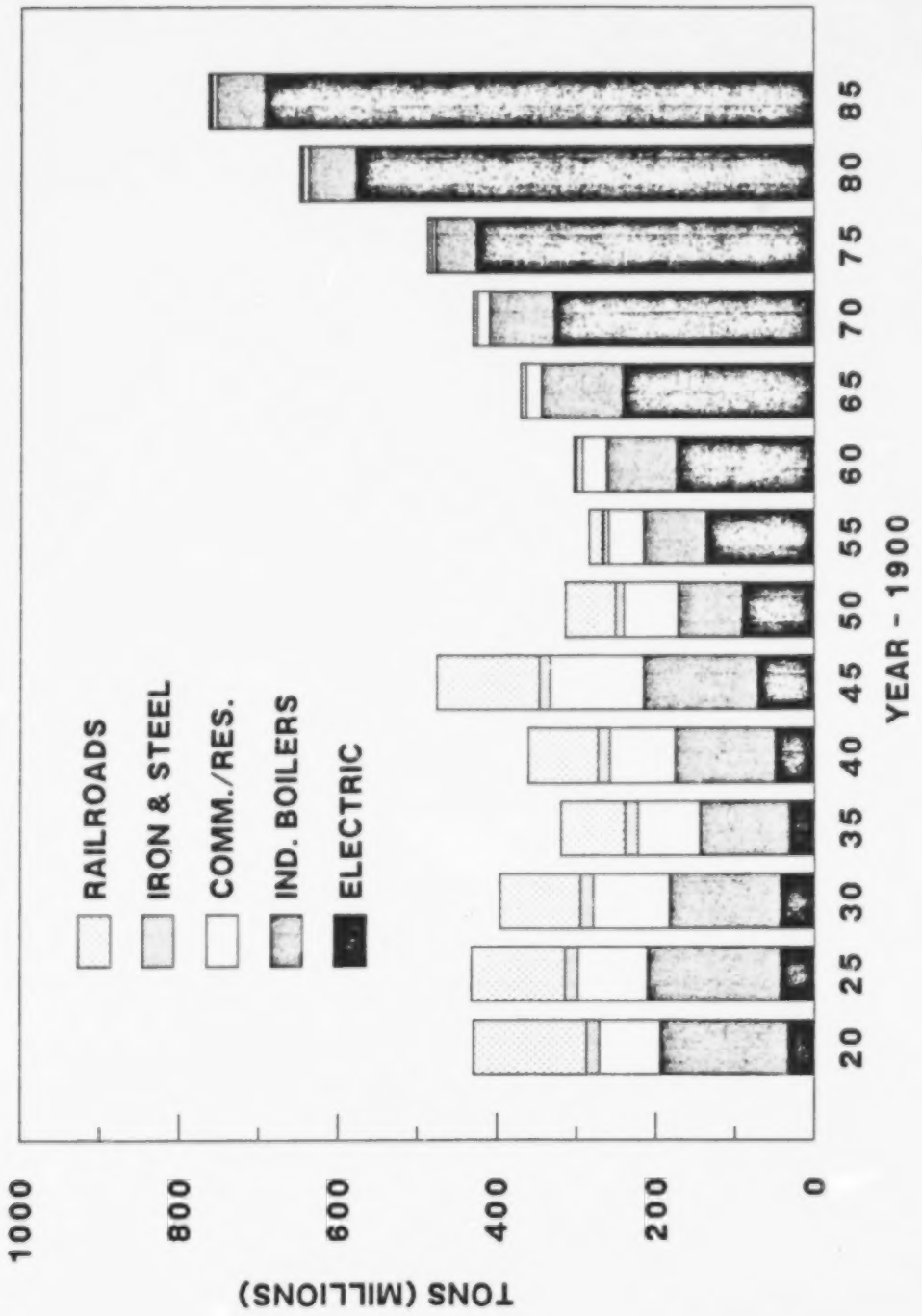
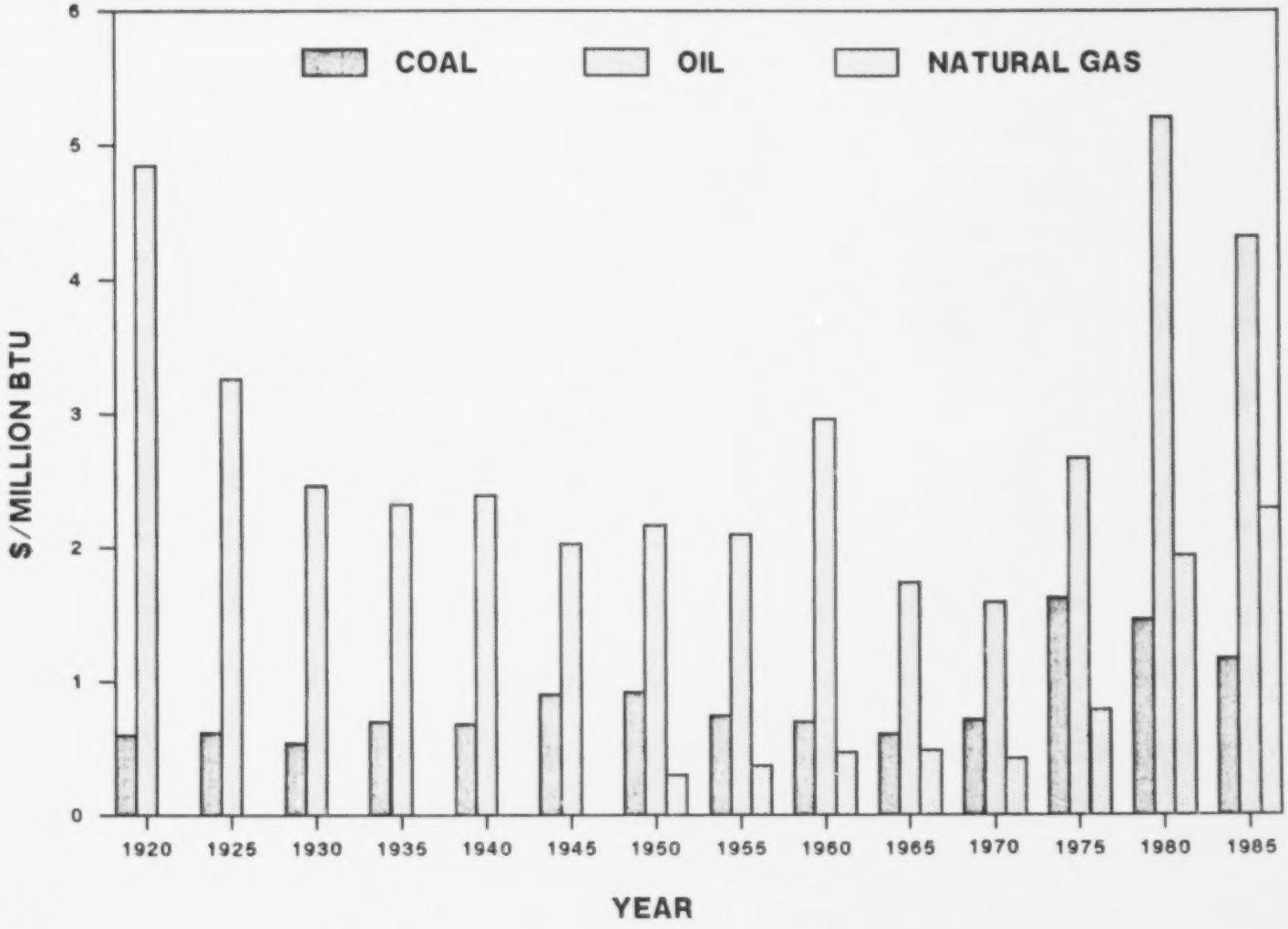

U.S. COAL USE 1920-1985
RAILROADS
IRON & STEEL
COMM./RES.
IND. BOILERS
ELECTRIC
TONS (MILLIONS)
1000
800
600
400
200
0
20 25 30 35 40 45 50 55 60 65 70 75 80 85
YEAR - 1900

FIGURE 5.

FIGURE 6. **U.S. FUEL COSTS (1986 DOLLARS)**



costs. Since about 1970, gas costs have risen substantially and moved ahead of coal costs in the late 1970s. This price differential between coal and oil (and natural gas) is expected to remain in the foreseeable future. This would tend to make coal the fuel of choice where it can be used consistent with environmental regulations and other operating and technical constraints.

Environmental Problems

Unfortunately, the utilization of coal involves major environmental and safety problems throughout the fuel cycle. From mine safety and strip mining's ecological damage to air pollution associated with coal combustion to the ultimate disposal of fly ash and sulfur sludge, coal use presents major environmental challenges. Perhaps the most important of these is to control emissions of important air pollutants associated with coal combustion. Table 1 describes the major regulated (criteria) and currently unregulated pollutants for which coal combustion is an important source. Sulfur oxides, nitrogen dioxide, and particulates are all currently regulated for both new and existing sources under the U.S. Clean Air Act. Nitrous oxide and carbon dioxide are currently unregulated. Table 1 summarizes for each of these pollutants the major health and environmental concerns and the role of coal relative to other sources of pollution.

The Clean Air Act

The driving force for regulations dealing with air pollutants associated with coal combustion is associated with the Clean Air Act. Industrialization and the motor vehicle, hallmarks of twentieth century prosperity, created pollution problems unknown to past generations. In the 1960s and 1970s the U.S. Congress responded to the growing U. S. concern about environmental dangers by passing several ambitious environmental protection laws--the earliest, the Clean Air Act of 1970. Major amendments were enacted in 1977. The Clean Air Act activated a schedule to limit emissions of a variety of air pollutants from existing and new sources. The law required the U. S. EPA to set ambient air quality standards (AAQS) for major pollutants. Today standards are in effect for six pollutants called the criteria pollutants:

- sulfur dioxide (emitted by electric utilities, smelters, petroleum refineries, and industrial boilers)
- carbon monoxide (emitted by cars, trucks, and buses)
- particulates (emitted by electric utilities, industry, and motor vehicles)
- nitrogen oxide (emitted by electric utilities and motor vehicles)
- ozone (formed from hydrocarbons and nitrogen oxides emitted by industry and motor vehicles)
- lead (emitted from motor vehicles, lead smelting, and processing plants)

TABLE 1. IMPORTANT COAL-RELATED POLLUTANTS

	Health Concern	Environmental Concern	Coal Role
Criteria Pollutants			
Sulfur Dioxide	- Respiratory tract problems. - Permanent harm to lung tissue.	- Acid deposition damage to lakes, streams, & forests. - Visibility.	Coal combustion is dominant source.
Nitrogen Dioxide (NO_2)	- Respiratory illness and lung damage.	- Acid deposition. - Increased ozone: forest damage.	Coal combustion and autos are major sources.
Airborne Particulates	- Eye and throat irritation, bronchitis, lung damage.	- Visibility.	Coal has diminished in importance.

TABLE 1. IMPORTANT COAL-RELATED POLLUTANTS (CONTINUED)

	HEALTH CONCERN	ENVIRONMENTAL CONCERN	COAL ROLE
NON-CRITERIA POLLUTANTS			
NITROUS OXIDE (N_2O)	- SUSPECTED STRATOSPHERIC OZONE DEPLETION--SKIN CANCER FROM ENHANCED UV-B RADIATION.	- UV-B RADIATION ECOLOGICAL AND AGRICULTURAL DAMAGE (INFO. WEAK). CONTRIBUTIONS TO GLOBAL WARMING.	EMISSION FACTORS UNAVAILABLE. COAL APPEARS IMPORTANT.
CARBON DIOXIDE	- MAJOR IMPACTS OF GLOBAL CLIMATE WARMING. INDIRECT HEALTH IMPACTS UNKNOWN.	- DESTRUCTION OF SENSITIVE ECO SYSTEMS BY GLOBAL WARMING. INCREASED AIR POLLUTION.	COAL MOST IMPORTANT FUEL DUE TO LARGE USE AND HIGH CARBON/HYDROGEN RATIO.

As indicated by the information contained on Table 1, coal combustion is particularly important for three of these criteria pollutants, namely sulfur dioxide, nitrogen dioxide, and particulates. In order to meet these AAQS, states were required to submit to EPA State Implementation Plans (SIPs) specifying how they would protect clean air areas from degradation and how they would achieve AAQS by 1982 and 1987 deadlines. SIPs specify emission limits for major pollution sources such as coal-fired power plants and establish timetables for polluters to comply with the limits. This is the mechanism by which certain coal-fired power plants located in polluted areas have been retrofitted with scrubbers or switched to low-sulfur coal in major industrialized areas in the U. S.

The Clean Air Act also authorizes EPA to set emission standards from new stationary pollution sources. New Source Performance Standards (NSPS) typically apply to major industrial facilities. NSPS are set at levels reflecting the best technology "adequately demonstrated." EPA considers costs, non-air quality health and environmental impacts, and energy requirements. The most important NSPSs relating to coal are those for electric power plants and industrial boilers, both of which require 90 percent control for high sulfur (greater than about 2 percent) coal. The impact of the Clean Air Act on emissions associated with coal combustion has varied substantially depending on the pollutant regulated. Figure 7 shows air pollutant emissions from U. S. coal between 1920 and 1985. As one can see, particle emissions were quite high earlier in this century since many of the end uses for coal involvedlittle or no particulate cleanup. For example, residential furnaces and steam locomotives emitted particulates without effective control. As coal became used for electric production and with the use of mechanical and later electrostatic precipitators, particulate emissions diminished substantially.

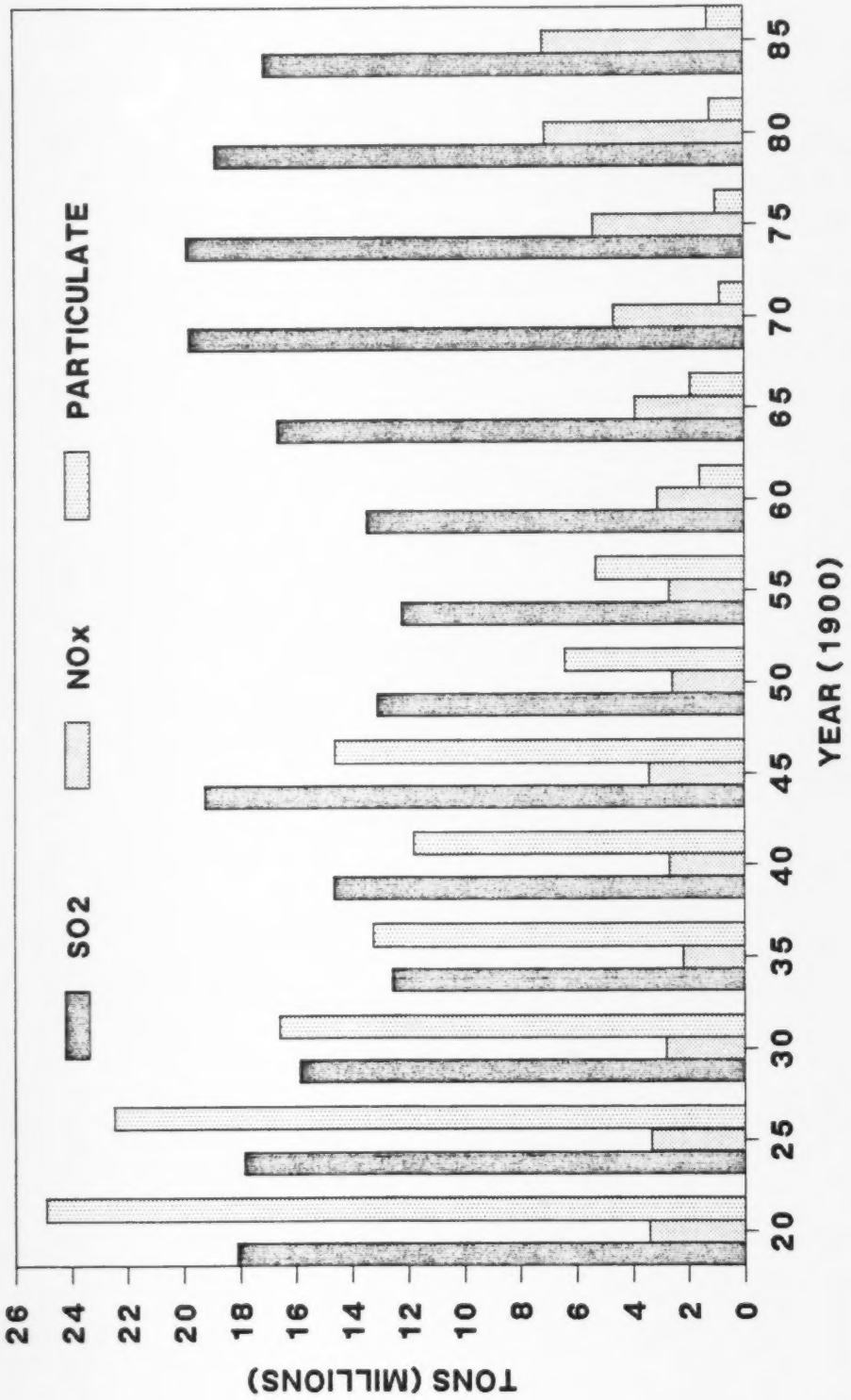
The impact of the Clean Air Act has basically kept utility particulate emissions at relatively low levels despite a major increase in coal use after 1970. The Clean Air Act, through both NSPSs and SIPs, has had a major impact on sulfur dioxide emissions since the Clean Air Act's passage in 1970. Emissions of sulfur dioxide were significantly decreased in that time period. The impact of the Clean Air Act on sulfur dioxide is even more dramatic when one compares emissions to what they would have been in the absence of regulation. I estimate that, in the absence of the Clean Air Act, sulfur dioxide emissions could have increased by more than 50 percent between 1970 and 1985.

As far as nitrogen oxide control is concerned, the Clean Air Act has not been particularly effective in reducing emissions from coal-fired boilers. Very little utility control is required by SIPs and NSPSs for nitrogen oxides since standards are based on low NO_x combustion modification technology.

It is interesting to note that U.S. air quality has improved substantially since the passage of the Clean Air Act, although pollution problems still remain widespread, according to EPA's "National Air Quality and Emissions Trends Report, 1985" released in April 1987. The following improvements in national average air quality levels from 1976 to 1985 are reported for the following important coal-related air pollutants:

- Sulfur dioxide levels improved 42 percent, and the estimated number of times the 24 hour AAQS was exceeded decreased 95 percent.
- Nitrogen dioxide levels improved 11 percent.
- Particulate levels improved 24 percent.

FIGURE 7. U.S. COAL AIR EMISSIONS



It should be recognized that ambient air quality is associated with many more pollution sources than just coal combustion, so that it is not generally feasible to directly relate the impact of coal combustion control to the improvements in U.S. air quality. However, for sulfur dioxide, where coal combustion is the dominant source, it is probably safe to say that the impact of the Clean Air Act on coal-fired power plants was a major factor in the important improvements in ambient sulfur dioxide levels.

The Clean Air Act encouraged development and commercialization of important sulfur dioxide and nitrogen oxide controls in order to meet the NSPS and SIP provisions. Of particular importance are flue gas desulfurization for sulfur oxide control and low nitrogen oxide burners for nitrogen oxide control. Flue gas desulfurization (FGD) is widely applied in the U. S. on coal-fired power plants with a commitment to over 100,000 MW of FGD capacity of the approximately 300,000 MW of U. S. coal-fired generating capacity.

Controlling Coal Combustion Pollution

Table 2 describes current and emerging technologies for sulfur dioxide and nitrogen oxide control. Included are control technologies available for current pulverized coal boilers as well as those that could be applied as new boiler technology with inherent SO_2/NO_x control capabilities. The table briefly describes the technology, the estimated levels of control on SO_2 and on NO_x, and estimated commercial availability, including comments primarily related to applicability. Note that the overwhelming choice of U.S. utilities for SO_2 control technology has been lime and limestone scrubbers (see Table 2). Note that my EPA Laboratory has been actively developing LIMB and E-SOx technologies which appear to be attractive retrofit alternatives and are summarized in Table 2.

In the U. S. there is much debate about whether the Clean Air Act should be amended by the Congress to mandate a decrease in emissions of both sulfur dioxide and nitrogen oxides from current levels. This debate is fueled by concern about acid deposition and its potential impact on lakes, streams, forests, and anthropogenic materials. Our Canadian neighbors have encouraged us to pursue an aggressive control program. The retrofitability of available and emerging technologies to existing coal-fired power plants is particularly important for any such program. If the U. S. wishes to make substantial reduction in current levels of SO_2 and NO_x in the near term, it will be necessary to retrofit many coal-fired power plants.

Recently, the Department of Energy has initiated their Clean Coal II program which is aimed at demonstrating cost effective retrofit and other clean coal technologies that could lower the cost of a major coal-fired power plant retrofit program aimed at acid deposition concerns. The Department of Energy is currently reviewing proposals with the aim of allocating $575 million for the demonstration of the most attractive alternatives to current lime and limestone scrubber technology.

Future Emissions of Coal Related Pollutants

Although I have focused primarily on past and current coal use and pollutant emissions, I would now like to discuss where the U.S. may be going in terms of pollutant emissions over the next several decades. As was indicated in Figure 3 earlier, coal use (especially for electrical production) is expected to increase dramatically over the next several decades. In order to evaluate pollutant emissions from coal combustion in the future, the ETAM 2 model (Reference: Draft

TABLE 2: SULFUR AND NITROGEN OXIDE CONTROL TECHNOLOGIES FOR COAL-FIRED BOILERS

Sulfur Dioxide Controls

Technology	Description	Control %* SO_2	Control %* NO_x	Estimated Commercial** Availability	Comments
Wet flue gas desulfurization	Limestone or lime in water removes SO_2 in a scrubber vessel. Additives may be used to enhance SO_2 removal. A wet waste or gypsum is produced.	70-97	0	Current for new boilers and retrofit.	Most economical for high sulfur coal and (FGD) large boilers. Certain retrofits difficult.
Dry flue gas desulfurization	Lime in water removes SO_2 in a spray dryer, which evaporates the water prior to the vessel exit. Produces a dry waste.	70-95	0	Current for low to moderate S coal for new boilers. High sulfur coal retrofit, 5 yrs.	Demonstration for high sulfur coal retrofit is necessary, but may be limited to 90% SO_2 removal.
$E\text{-}SO_x$, and duct injection	Lime and water are injected in a boiler duct and/or ESP ($E\text{-}SO_x$) and react with SO_2 similar to a spray dryer.	50-80	0	Pilot scale only. Demonstrations required, 3-7 yrs.	Potentially low cost retrofits. May be site-specific limits.
Limestone injection multi-stage burners (LIMB)	Low NO_x burners and upper furnace sorbent injection.	50-60	50-60	Wall, 1-2 yrs; T-fired, 3-4 yrs.	Demos in progress. Applicable to moderate S coal retrofits or low S coal new boilers due to limited capture.
	May use humidification to improve SO_2 capture and ESP performance.	70-80	50-60	Same	

TABLE 2: SULFUR AND NITROGEN OXIDE CONTROL TECHNOLOGIES FOR COAL-FIRED BOILERS (Continued)

Technology	Description	Control % SO_2	Control % NO_x	Estimated Commercial** Availability	Comments
		NO_x Controls			
Low NO_x burners (LNB)	Burner design controls coal/air mixing to reduce NO_x formation	0	50-60	Now, new boilers and retrofit.	Additional retrofit demonstrations desirable.
Reburning	Boiler fired with 80-90% coal. Remaining fuel (natural gas) is injected higher in boiler to reduce NO_x. Air added to complete burn-out. Sorbent may be injected to capture SO_2.	Without sorbent, 10-20; with sorbent, 50-60	50-85	Demos starting, available in 3 yrs.	May be only combustion NO_x control for cyclones Sensitive to natural gas price. New or retrofit.
Selective catalytic reduction (SCR)	Reacts NO with NH_3 over a catalyst at 500-700° F (260-370°C).	0	80-90	Pilot plant only in U.S., 4 yrs.	Catalyst cost and life main issues. Retrofit or new, if demos in U.S.
		SO_2/NO_x New Boiler Systems			
Atmospheric fluidized-bed combustion (AFBC)	Coal and air are burned in fluidized bed of sorbent which captures SO_2 and limits NO_x formation.	70-90	50-70	Now, for industrial boilers. Utility demo in progress (2-3 yrs).	Primarily for new boilers. Repowering (retrofit) applicability limited.

TABLE 2: SULFUR AND NITROGEN OXIDE CONTROL TECHNOLOGIES FOR COAL-FIRED BOILERS (Continued)

SO_2/NO_x New Boiler Systems (Continued)

Technology	Description	Control % * SO_2	Control % * NO_x	Estimated Commercial** Availability	Comments
Pressurized fluidized-bed combined cycle (PFBCC)	Coal burned in a fluidized bed at elevated pressure. Gas cleaned and run through gas turbine which generates electricity. Waste heat converted to steam to generate electricity.	90-95	70-80	Pilot plant data. DOE demo initiated, 5-10 yrs.	Primarily for new boilers. Repowering involves replacing virtually all existing plant equipment.
Integrated gasification combined cycle (IGCC)	Gasifier converts coal/ air to fuel gas, sulfur removed, and fuel gas burned in a combustion turbine. Waste heat used to generate steam. Electricity generated by both combustion and steam turbines.	95-99	40-95	Cool-water demo currently operating but economics questionable. Two DOE demos initiated, 5-10 yrs.	See PFBCC comments. Also, economic operation depends on hot fuel gas cleanup and high temperature turbines which are not demonstrated.

* Control efficiency is % reduction from emission levels for uncontrolled coal-fired power plants.

** Estimated commercialization for some technologies is strongly dependent on successful demonstrations.

report "The Environmental Trends Analysis Model: Technical Document," prepared for U. S. Department of Energy's Office of Policy, Safety and Environment, March 1984) has been run to study various economic growth and emission control scenarios. This allows us to look at the impact of various regulatory programs on future emissions of important coal air pollutants. The general assumptions for these model runs are described in Table 3.

Projections for Sulfur Dioxide Emissions

For sulfur dioxide, four cases were examined: a business-as-usual case (the base case with no modification to the Clean Air Act or to current new source regulations), and three additional cases with the assumptions listed in Table 4 (assuming varying levels of control for new and existing sources). For example, the new plant technology case assumes integrated coal gasification combined cycle (see Table 2) to be commercially available for all new systems installed after 1995. It is further assumed that such systems are capable of 99 percent sulfur dioxide removal. Although this is not deemed a credible case, since it doesn't appear reasonable to expect commercial dominance of this technology by 1995, it at least shows the best that can be achieved with technology dealing only with new sources. The revised NSPS case assumes that the NSPS will be revised to enhance sulfur dioxide collection to the 95 percent reduction level by utilities by 1995 and an additional 50 percent reduction of emissions by industrial boilers by the year 2000. The acid rain control case looks at retrofitting coal-fired utilities to achieve a 0.9 lb per million Btu limit once a plant has reached 30 years of age. This is one of many acid rain control scenarios being discussed in the U. S. and should probably be considered a middle-of-the-road plan. It is on neither the high end nor the low end of stringency of programs being discussed by the U.S. Congress.

Figure 8 shows the results of projections from 1990 through 2030 using 1980 as the basis for the projection calculations. (Note that the quality of the value for 1985 is questionable since it was derived from other than the historical data in the 1920-1980 timeframe and is probably best ignored for the purposes of evaluating the projection scenarios.) One can see that the impact of an acid rain control case on emissions occurs relatively soon. A major reduction over 1980 levels is possible by the year 2000. However, emissions tend to increase beyond 2010 since new power plants are being added, thereby increasing overall sulfur dioxide emissions. The revised NSPS case shows some reduction over the base case, but major reductions are not achieved until the year 2030 as the older, higher emitting existing power plants are retired. The new plant technology case, assuming integrated coal gasification combined cycle, shows a similar delayed impact on sulfur dioxide emissions but ultimately a more dramatic reduction in light of the assumption that 99 percent control would be achieved by all new units installed after 1995. As indicated earlier, this is not considered a credible scenario. It does show that dealing only with new sources delays impacts on emissions well into the next century. This supports my previous claim that retrofitting is necessary if near term results are required.

We have also run a case not shown on Figure 8 which would represent a combination of an acid rain and a revised NSPS case. As one would expect, you get the synergistic benefits of near term reduction of sulfur dioxide due to retrofitting and a sustained reduction based on the fact that new sources will be even lower emitters than current new sources would be in the absence of a tighter NSPS.

TABLE 3. GENERAL ASSUMPTIONS FOR ETAM 2 RUNS

60-YEAR UTILITY COAL PLANT LIFETIME

2.0% ECONOMIC GROWTH

1.15% ENERGY GROWTH

1980 NAPAP UTILITY DATA FROM PECHAN

1980 INDUSTRIAL DATA FROM EEA

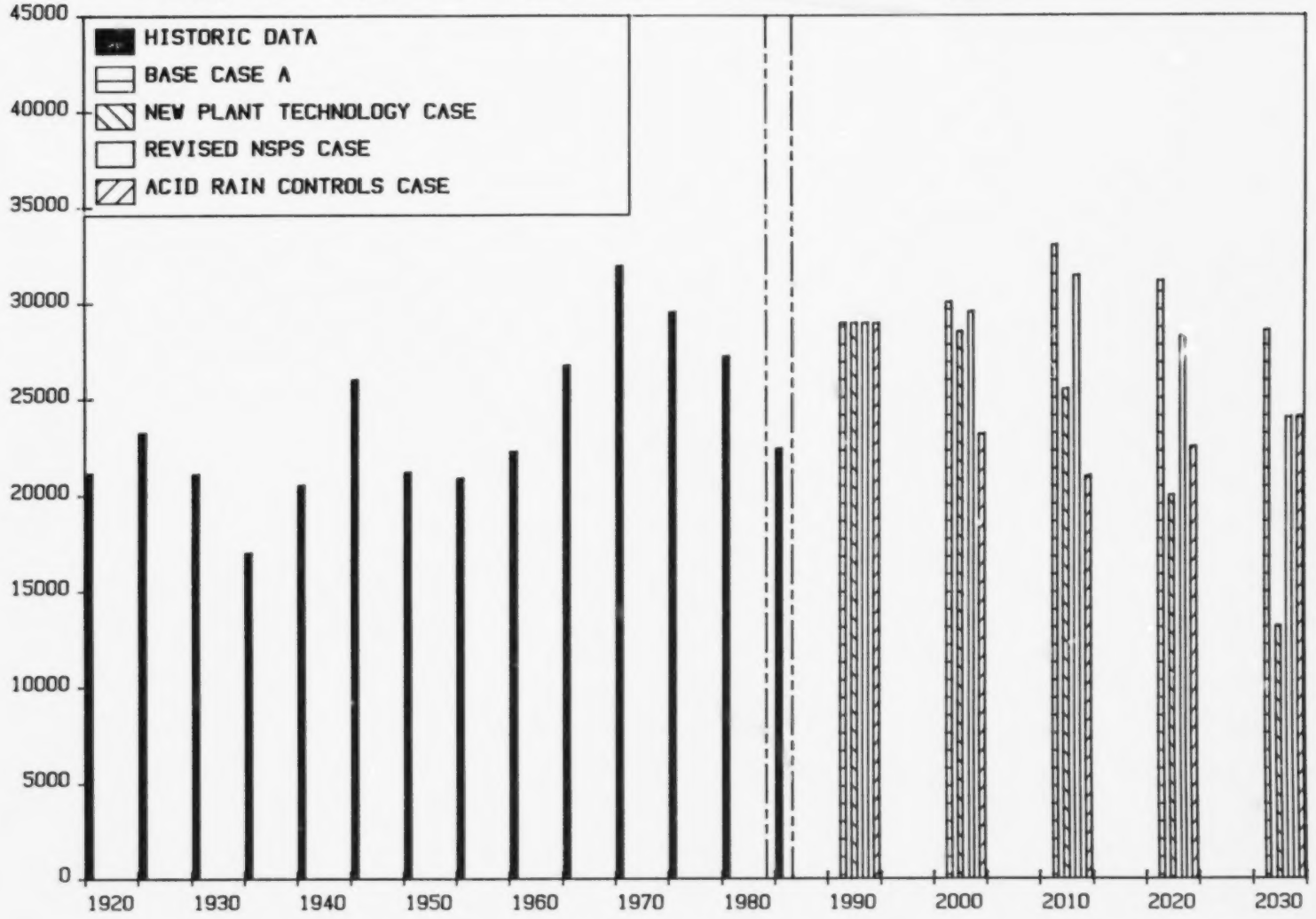
NUCLEAR PEAKS AT ~115 GW IN 2000, ~85 GW IN 2010 AND BEYOND

UTILITY COAL USE IN 2010 ABOUT 2.5 TIMES 1980 LEVELS

TABLE 4. **CASE-SPECIFIC SO_2 ASSUMPTIONS**

NEW PLANT TECHNOLOGY	99% SO_2 REMOVAL AFTER 1995
REVISED NSPS	95% REDUCTION BY UTILITIES (1995) (UNCONTROLLED)
	50% REDUCTION BY INDUSTRIAL BOILERS (2000)
ACID RAIN CONTROLS	UTILITIES - 0.9 LB/MMBTU AFTER 30 YEARS OF PLANT LIFETIME

FIGURE 8. TOTAL SO2 EMISSIONS (Thousands of Tons)



Projections for Nitrogen Oxide Emissions

Table 5 presents the case specific nitrogen oxide assumptions. Again, new plant technology is based on capabilities of the technology such as integrated IGCC, but again the 1995 commercialization date is not realistic. Also note that the revised NSPS includes a mobile source reduction as well as a reduction in utilities and industrial boilers. Also note that the retrofit acid rain control case varies by firing type since cyclones, for example, are more difficult to control to a given nitrogen oxide level than tangentially fired boilers.

Figure 9 summarizes projections for nitrogen oxide emissions to the year 2030 including historical information from 1920 through 1985. Note that, in this case, the acid rain control case has only a moderate impact over the base case (business-as-usual case). Also note that the revised NSPS case again would have a delay in terms of its impact on emissions. However, beyond the next 20 or 30 years it would have a significant impact as new sources would be cleaner than those required under the current NSPS. Unlike the other options, the new plant technology case is able to keep projected nitrogen oxide emissions at about current levels. Also note that the new plant technology case results for nitrogen oxides are more realistic than those for sulfur dioxide since nitrogen oxide reductions could be achieved by selective catalytic reduction technology (Table 2) rather than relying on a technology such as IGCC which will likely not be ready in 1995.

Projected Nitrous Oxide Emissions

Figure 10 projects nitrous oxide emissions. As described in Table 1, nitrous oxide appears to be an important depleter of stratospheric ozone, which protects us from harmful UV-B solar radiation. It is also a thermally radiative trace gas contributing to global warming trends. The same assumptions for nitrogen oxide control scenarios contained on Table 5 were applied to our nitrous oxide projections. It was assumed that between 20 and 25 percent of nitrogen oxide emissions are nitrous oxide. This is a very crude and probably inaccurate assumption, but the best we can do with our current state of knowledge. As you can see the results are quite similar to those for nitrogen oxides: none of the approaches yield major reductions and only the new plant technology case is able to at least keep nitrogen oxide levels from escalating substantially over the next several decades.

Projected Carbon Dioxide Emissions

Finally, we took a look at carbon dioxide emissions from coal-fired power plants. In this case, rather than looking at regulatory scenarios which really don't impact carbon dioxide emissions significantly, I looked at economic growth rate since it drives coal use. Figure 11 shows carbon dioxide emissions as a function of three assumed growth rates. There is no feasible technology to control carbon dioxide emissions from coal-fired boilers. We are thereby left with only the alternative of burning less coal if we are serious about reducing such emissions over an uncontrolled or business-as-usual case.

Conclusions

Increasing coal use is vital to the economic well being of the U. S. I believe, with proper applications of controls, the projected increased coal use can be accomplished without unacceptable levels of sulfur and nitrogen oxides, particulates, and nitrous oxide. For carbon dioxide and its projected impact on global warming, my optimism fades. Barring a technology breakthrough of major proportions (e.g., successful commercialization of nuclear fusion or solar electric generation), the best we can hope for is to moderate emissions of carbon dioxide from the combustion of coal and other fuels through conservation.

TABLE 5. CASE-SPECIFIC NO_X ASSUMPTIONS

NEW PLANT TECHNOLOGY	90% NO_X REMOVAL AFTER 1995
REVISED NSPS	50% REDUCTION BY UTILITIES (1995) AND INDUSTRIAL BOILERS (2000)
	25% REDUCTION BY MOBILE SOURCES (2000)
ACID RAIN CONTROLS	VARIES BY FIRING TYPE -0.3 LB/MMBTU - TANGENTIAL -0.4 LB/MMBTU - WALL-FIRED -1.0 LB/MMBTU - CYCLONE

FIGURE 9. TOTAL NOX EMISSIONS (Thousands of Tons)

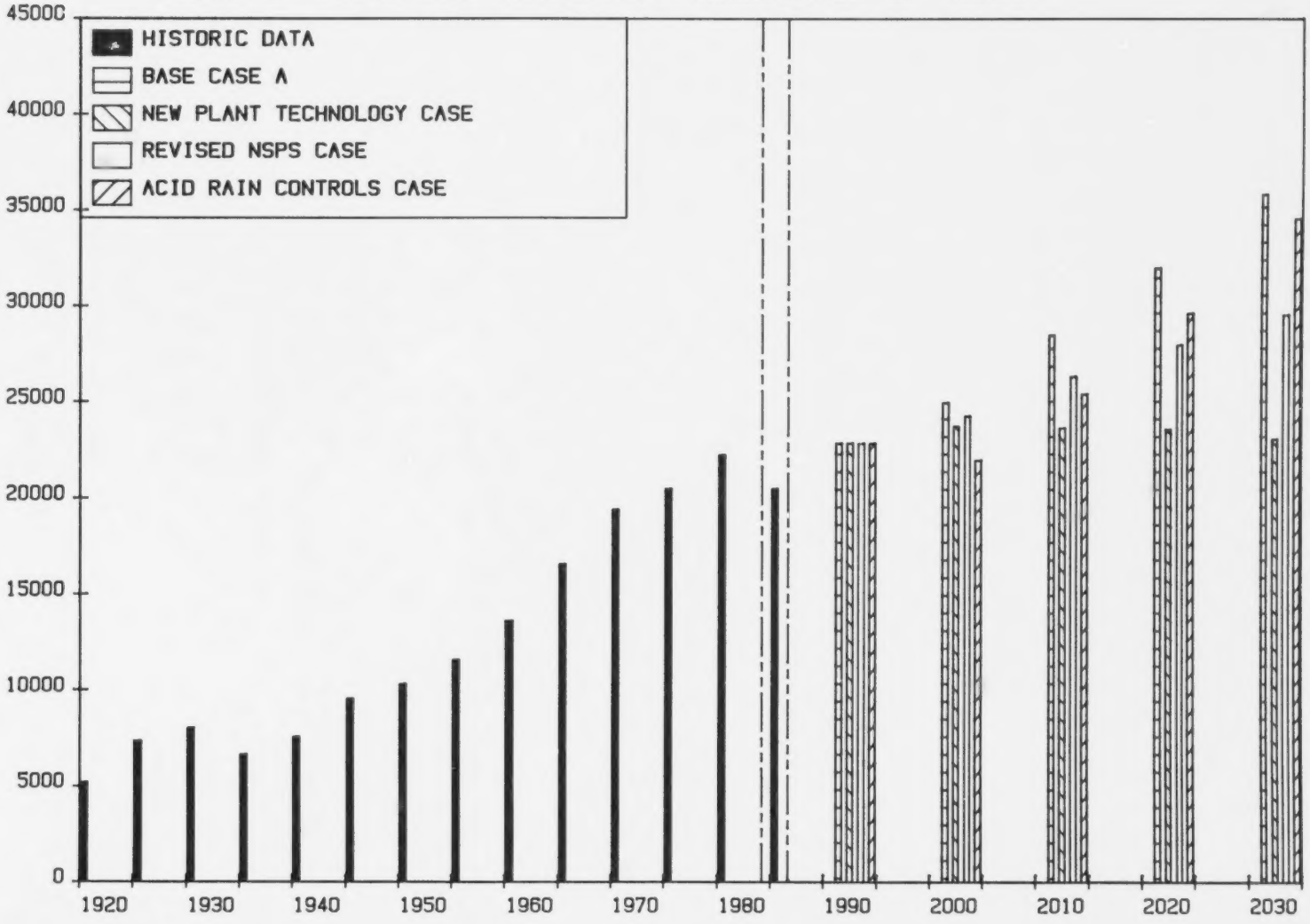


FIGURE 10. TOTAL N2O EMISSIONS (Thousands of Tons)

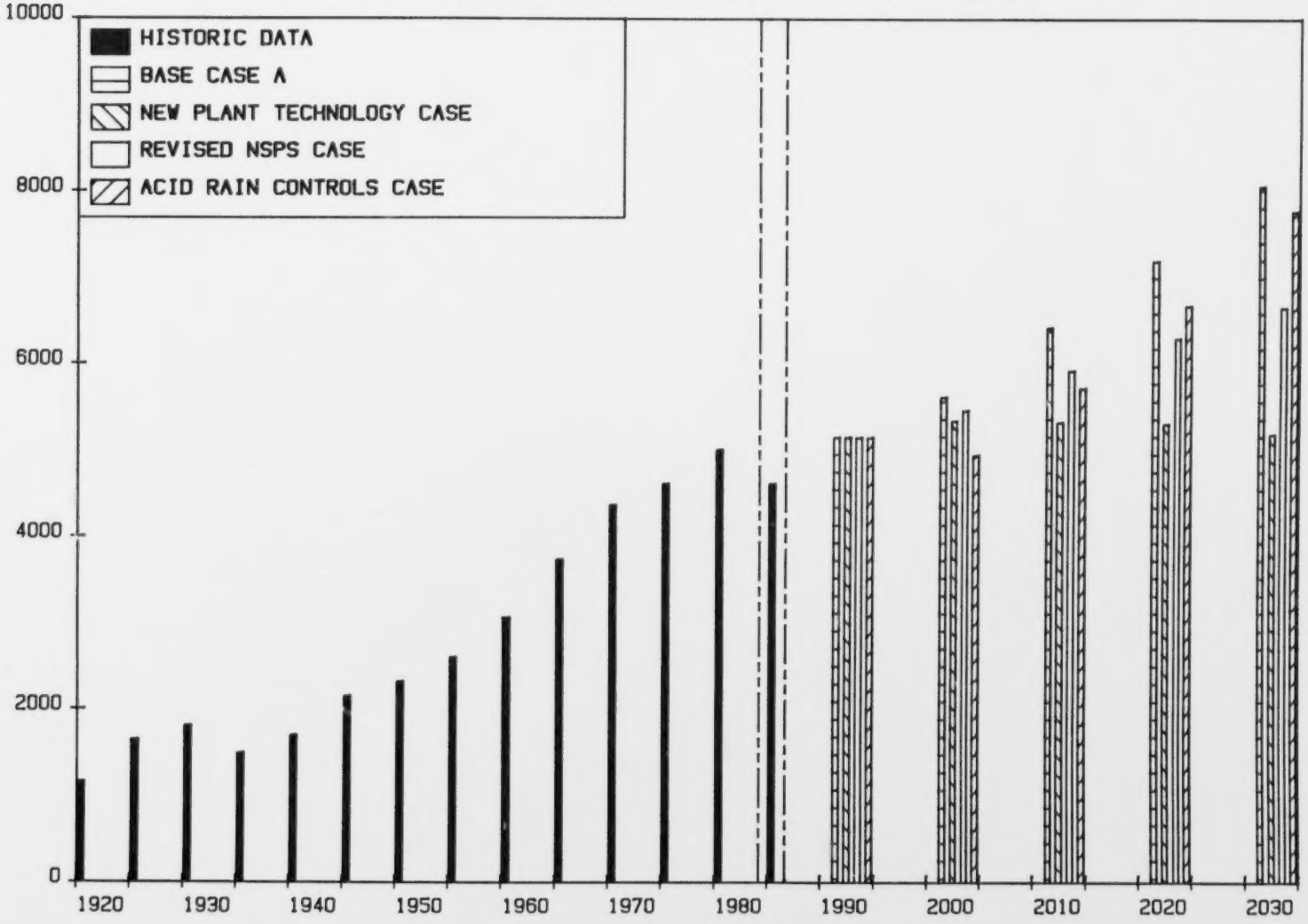


FIGURE 11. TOTAL CO2 EMISSIONS (Millions of Tons)